DOT/FAA/CT-88/8-2

CHAPTER III

SECTION 1.0

CONVENTIONAL PNEUMATIC BOOT DEICING SYSTEMS

CHAPTER III—ICE PROTECTION METHODS

CONTENTS

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

Symbol	Description
Btu	British Thermal Unit
°C	Degrees Celsius
cm	Centimeter
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
ft	Feet or foot
gpm	Gallons per minute
hp	Horsepower
kg	Kilogram
kN	KiloNewton
lbf	Pounds force
lbs	Pounds
m	Meter
mm	Millimeter
psig	Pounds per square inch gauge (pressure)
scfm	Standard cubic feet per minute

III.1. CONVENTIONAL PNEUMATIC BOOT DEICING SYSTEMS.

III.1.1 OPERATING CONCEPTS AND COMPONENTS.

Pneumatic boot systems have been the standard ice protection method for piston engine aircraft since the 1930s. The boot surfaces remove ice accumulations mechanically by alternately inflating and deflating tubes within a boot that covers the surface to be protected. Inflation of the tubes under the accreted ice breaks the ice into particles and destroys the ice bond to the surface. Aerodynamic forces, and centrifugal forces on rotating airfoils, then remove the ice. This method of deicing is designed to remove ice after it has accumulated rather than to prevent its accretion on the surface; thus, it cannot be used as an anti-icing device.

Conventional pneumatic boots are constructed of fabric-reinforced synthetic rubber or other flexible material. The material is wrapped around and bonded to the leading-edge surfaces to be deiced on wings or empennage. Total thickness of typical pneumatic boots is usually less than 0.075 inch (1.9 mm). Pneumatic boots are easily retrofitted, require very little power, and are a lightweight system of reasonable cost.

The tubes in the pneumatic boot are usually oriented spanwise but may be oriented chordwise if dictated by a particular design. When inflated, chordwise tubes have lower drag than spanwise tubes but may present manifolding complications. The inflatable tubes are manifolded together in a manner to permit alternate or simultaneous inflation as shown in figures III 1-1 and III 1-2, but alternate inflation is less commonly used. Chordwise, the extent of deicing coverage should be determined by analysis or test of droplet impingement limits (see section I.2.2.1). Spanwise coverage should be sufficient to protect the surface in question.

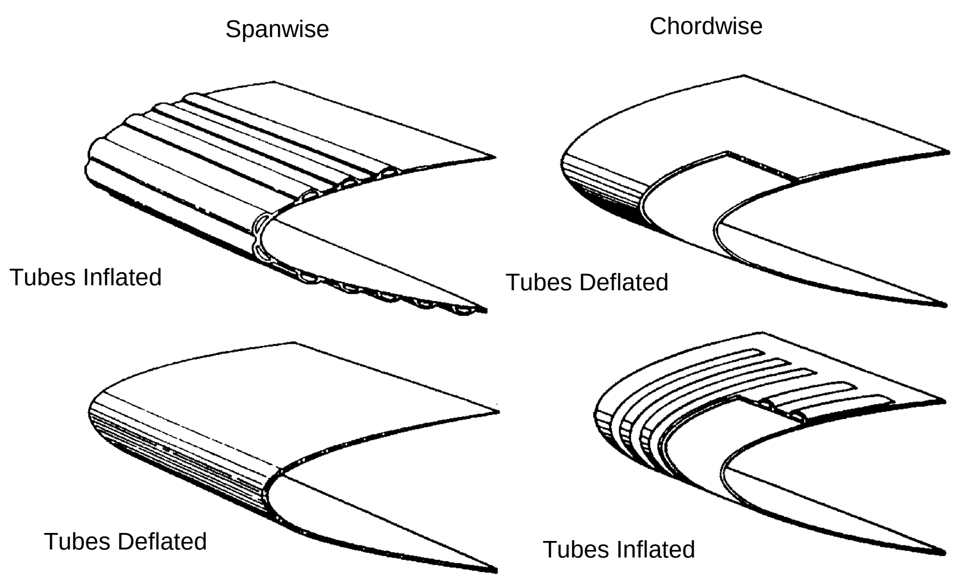


FIGURE III 1-1. INFLATABLE DEICING TUBES

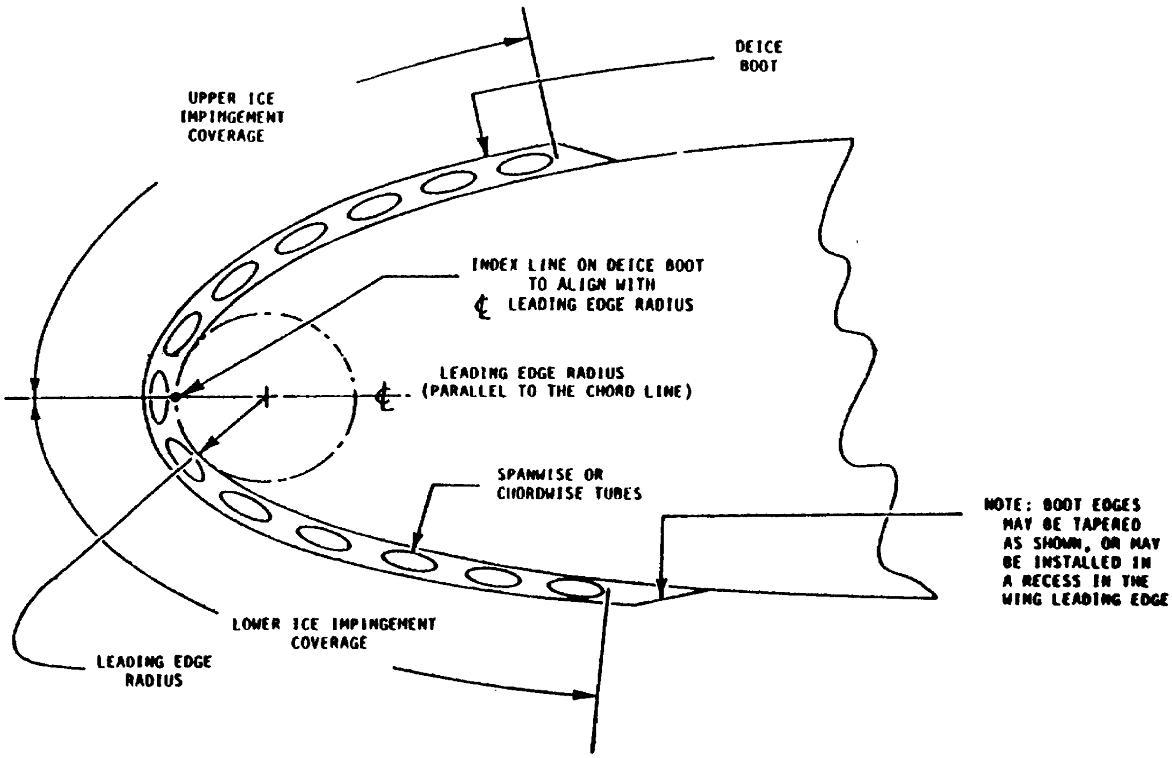


FIGURE III 1-2. TYPICAL DEICING BOOT INSTALLATION

In addition to the boots, the primary components of a pneumatic system are a regulated pressure source, a vacuum source, and an air distribution system. Miscellaneous components may include check and relief valves, air filters, control switches and timer, and electrical interfaces including fuses and circuit breakers. A regulated pressure source is required to insure expansion of all tubes in the system to design limits and within design rise times. If tube expansion is too slow, deicing effectiveness is lessened. The vacuum source is essential to insure positive deflation and keep the tubes collapsed during nonicing flight conditions to minimize the aerodynamic penalty.

Air pumps generally multiply the atmospheric pressure by a fixed factor, so the pressure delivered becomes a function of altitude. Therefore, for air pump systems, the pressure produced at service ceiling altitude is a design condition.

Some characteristics of a conventional pneumatic boot system are listed below:

• Surface Ply Elongation	40% to 50%
• Nominal Inflation Time	Five seconds
• Nominal Deflation Time	Six seconds
• Maximum Surface Distortion	0.375 in. (9.53 mm)
• Threshold Ice Removal Thickness	0.25 in. (6.35 mm)
• Surface Ply Material	Elastomeric

A new pneumatic boot design has recently been developed that removes thin ice (down to 0.06 inch) on thin airfoils. The boot uses deicing tubes that are a fraction of the size of conventional boot tubes and are inflated by higher air pressures for less than 1 second.

III.1.2 DESIGN GUIDANCE.

III.1.2.1 Fixed-Wing Aircraft.

Boot deicing is strongly affected by the airfoil shape. The boot manufacturer's assistance is usually needed in the determination of tube size, sequencing order, pressure level, spanwise or chordwise tube combinations, and other attributes.

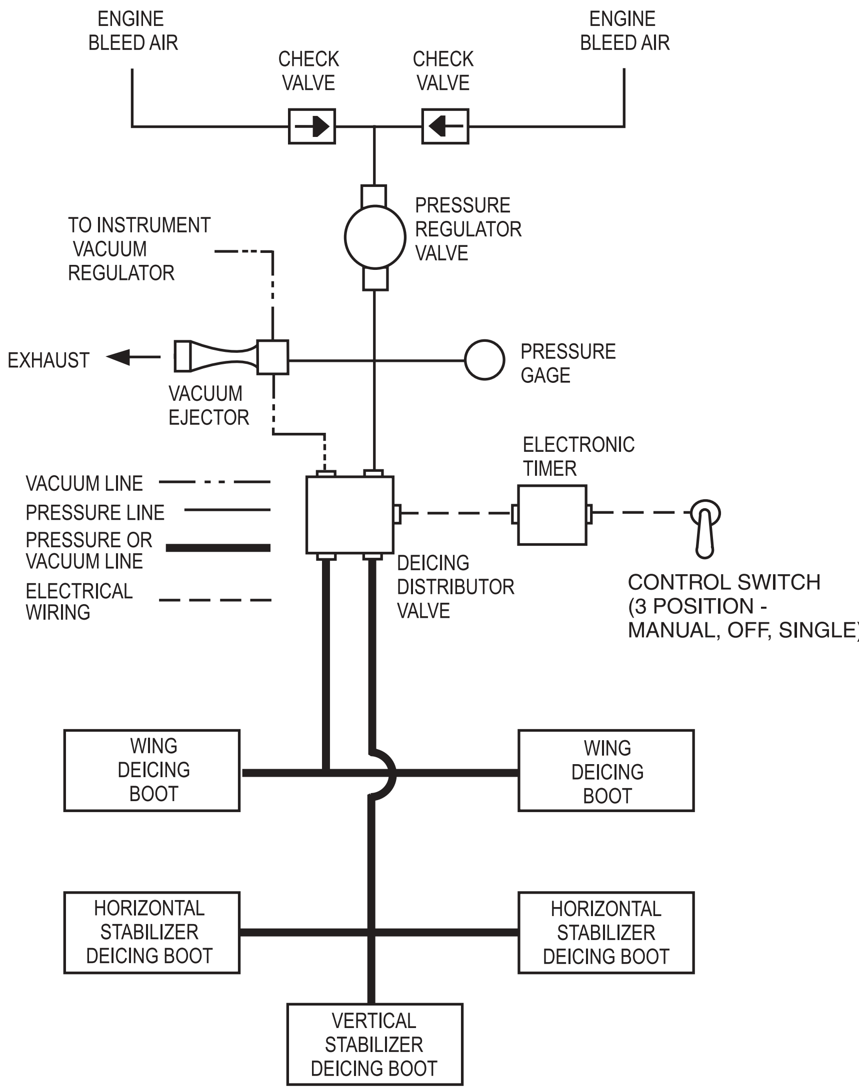
The system should be operated to evaluate overall performance during dry air flight testing. Boot inflation pressure should reach the design pressure within the allowable inflation time (usually about 5 or 6 seconds). This pressure should be maintained up to the maximum icing altitude of 22,000 feet (6100 m) (see FAR 25, Appendix C) or the aircraft's service altitude, whichever is lower. Also, the vacuum used to deflate the boots should be adequate even at maximum operating airspeeds.

III.1.2.1.1 Turbine Engine-Powered Aircraft.

Gas turbine engines generally provide pressure directly from compressor bleed air and vacuum from a bleed air driven ejector.

Components of a typical pneumatic boot surface deicing system for a twin turbine-powered aircraft are shown schematically in figure III 1-3. This typical system uses engine bleed air for the air pressure source, which is regulated to 18 lb/in^2 (124 KN/m^2) for boot inflation. As a safety feature, a relief valve is incorporated into the regulator valve design that will limit the over-pressure. For the dual-cycle system shown, the wing and empennage boots may be alternately pressurized.

The regulated bleed air is routed to a venturi air ejector which provides vacuum for boot hold-down, as well as for flight instruments. A distributor valve applies pressure or vacuum to the boots in conformity with a selected cycle. Usually this valve has two boot distribution ports: one port is used to inflate and deflate the wing boots and the other port is used for the empennage boots. An alternate distributor valve has a single inflation port and incorporates an ejector for vacuum. Air plumbing line sizes and system components are selected based on the functional requirements; namely, maximum boot operating pressure and the pressure rise time. Installation of this type of system requires only minor airframe modifications.



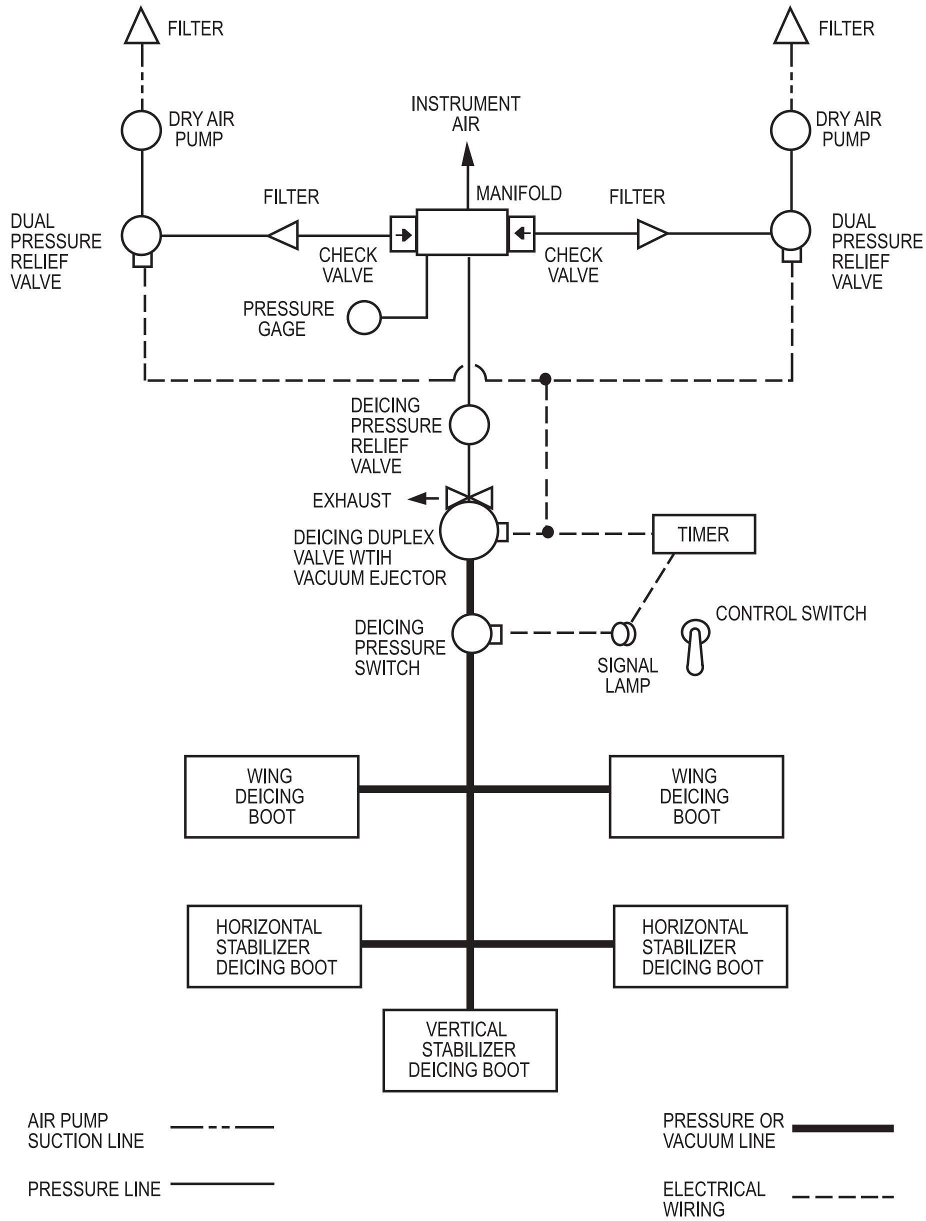
Dual Cycle System

FIGURE III 1-3. PNEUMATIC BOOT SURFACE DEICING SYSTEM—TURBINE ENGINE-POWERED AIRCRAFT

III.1.2.1.2 Reciprocating Engine-Powered Aircraft.

For piston engine aircraft, air pumps driven from the engine's geared accessory drive are usually used. Some manufacturers use the inlet and outlet sides of a sliding vane air pump to provide both vacuum and pressure. If only the outlet side of the air pump is used, a dual-pressure regulator and control valve are necessary to supply low-pressure air to the flight instruments and to an air injector for deicer system vacuum, and also the higher-pressure air required for boot inflation. Engine manifold vacuum is not suitable due to its extreme variability with engine load, and with turbo-charged engines, no manifold vacuum exists. Vacuum systems are often shared with vacuum-driven flight instruments.

Components of a typical pneumatic boot surface deicing system for a reciprocating engine-powered aircraft with positive air pressure flight instruments are shown in figure III 1-4. Engine-driven dry-air pumps supply air pressure for boot inflation. Dual pressure regulator and relief valves control the pressure at a low pressure setting that is adequate for instrument operation. When the surface deicing system is activated, the dual pressure regulators shift to the higher pressure required for pneumatic boot inflation. This two-stage pressure control provides extended pump life and less engine power extraction in normal flight without icing conditions.



Single Cycle System

FIGURE III 1-4. PNEUMATIC BOOT SURFACE DEICING SYSTEM—TWIN RECIPROCATING ENGINE-POWERED AIRCRAFT

A timer operates the solenoids in the pressure regulators and the deicing valve. A pressure switch operates a signal lamp to show boot operation.

The pressure regulator and relief valve system maintains pressure when the deicing system is in use. The deicing valve is a solenoid-operated on-off valve which applies pressure or vacuum to the boots. An air ejector is included in the system to provide vacuum to the boots in the off valve position. A single-cycle system where all boots are pressurized together is shown in figure III 1-4.

III.1.2.2 Rotorcraft.

An experimental pneumatic boot deicing system has been successfully tested on helicopter rotor blades (references 1-1 and 1-2). A deicing boot configuration was developed (figure III 1-5) to minimize aerodynamic drag when the boot was inflated. In this test, the inflated boots caused a drag increase equivalent to about 3/8 inch (0.95 cm) ice on the rotor blades. For a 9500-lb (4310-kg) 2-blade helicopter, full span deicing boots were simultaneously inflated in less than 2 seconds to effectively remove accreted ice. Operating air pressure was obtained from a turbine engine bleed source. Figure III 1-6 shows the operating schematic of this system. Improved ice shedding indicated that the boot rubber surface had a reduced surface adhesion to the ice.

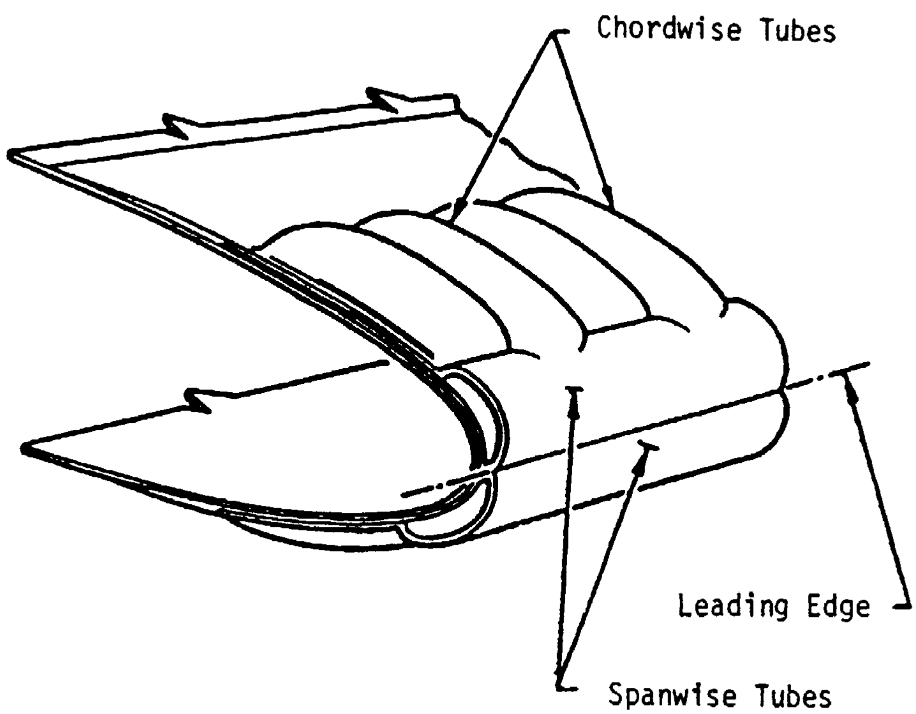


FIGURE III 1-5. ROTORCRAFT BLADE PNEUMATIC BOOT

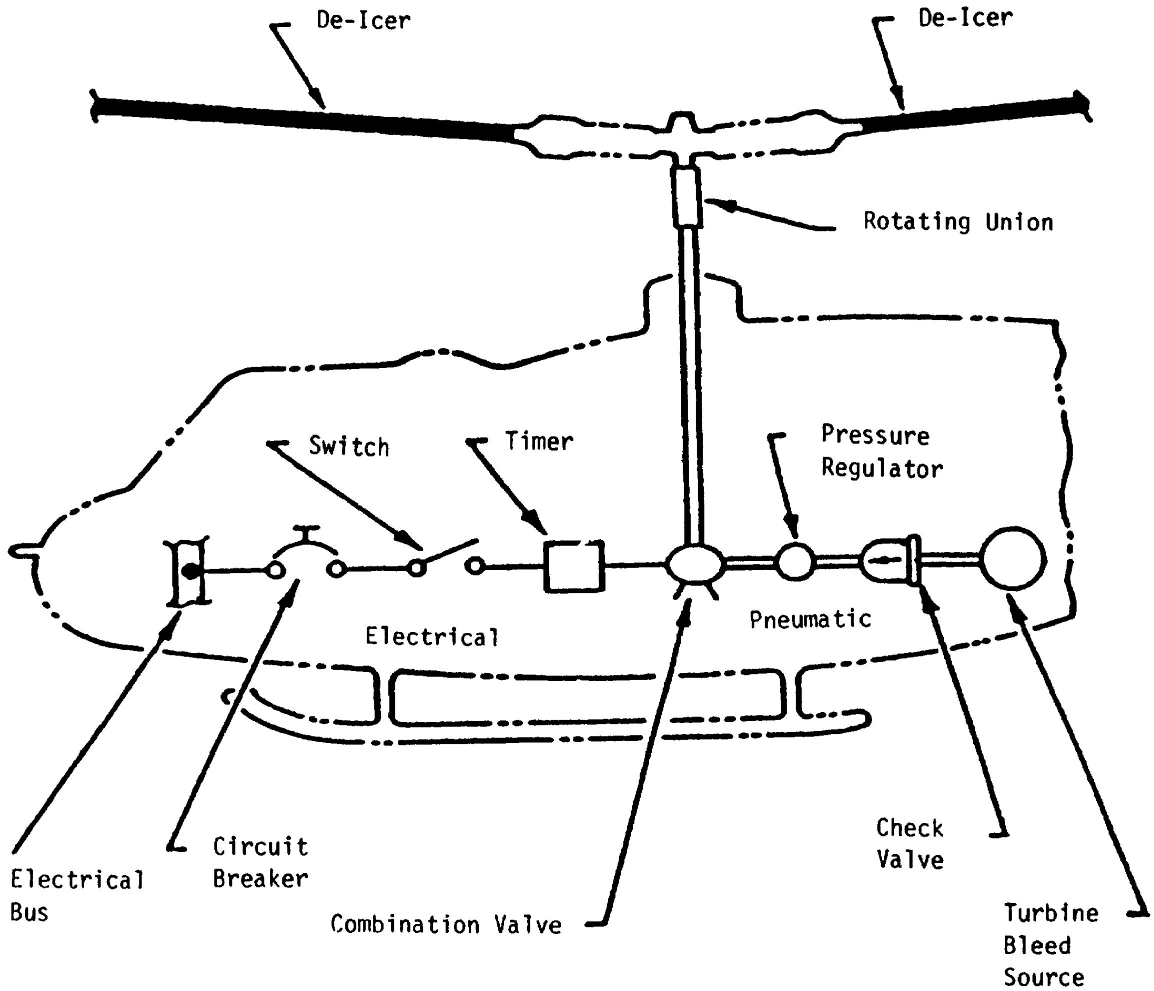


FIGURE III 1-6. ROTORCRAFT PNEUMATIC BOOT DEICING SYSTEM—SCHEMATIC

III.1.2.3 Other Applications.

Ice protection of some other components, such as radomes, with pneumatic boot deicing systems is feasible (see section III.1.3.8).

III.1.3 USAGES AND SPECIAL REQUIREMENTS.

III.1.3.1 Airfoil and Leading-Edge Requirements.

The airflow required for pneumatic boot operation is small compared with that for a hot gas ice protection system. Pneumatic boot deicing systems may be added to an existing airplane with minor modification and expense. In areas of low static pressure on airfoils, autoinflation of pneumatic boot tubes may occur and disrupt airflow over the surface. A vacuum source is used to prevent autoinflation during the deflation period. During the inflation portion of the cycle, large drag increases and lift degradation can occur because of the spoiler action of inflated spanwise deicing tubes. The use of chordwise tubes minimizes this problem.

Ice particles shed by pneumatic boots may be large enough to damage aft-mounted engines or propellers. Axial flow engines (turbojets and turbofans) are the most vulnerable, while turboprop engines with particle-separating inlet ducts are less likely to be damaged. For some airplanes, the wing section upstream of the engine may be provided with some form of anti-icing to avoid engine ice ingestion while the remainder of the wing is deiced by pneumatic boots. The silver pneumatic boots have the capability of removing thinner ice accretions (1/8″) which will not damage rear-mounted pusher propellers. Such a system has been certified on aft-mounted propeller aircraft.

III.1.3.2 Windshields.

The application of pneumatic boots for windshields is not possible.

III.1.3.3 Engine Inlet Lips and Components.

The use of pneumatic boots has been limited to ice protection of turbine engines with bypass inlets.

III.1.3.4 Turbofan Components.

The use of pneumatic boots for turbofan components has not been tried.

III.1.3.5 Propellers, Spinners, and Nose Cones.

The use of pneumatic boot deicing on propellers, spinners, and nose cones is feasible but has not been tried.

III.1.3.6 Helicopter Rotors and Hubs.

Pneumatic boot deicing systems have been tried on helicopters on an experimental basis using a 9500-lb (4310-kg) 2-blade helicopter (references 1-1 and 1-2) as discussed in section III.1.2.2. No application to rotor hubs is known.

III.1.3.7 Flight Sensors.

Pneumatic boot systems are not suitable to deice flight sensors.

III.1.3.8 Radomes.

Radar-designed pneumatic boot deicers may be installed on the external contour of radomes; however, the boot may slightly increase transmission losses. A schematic of a pneumatic boot system applied to a radome is shown in figure III 1-7. This system inflates all tubes at the same time. A combination valve provides deflation vacuum or inflation air as determined by a control timer. Installation details are shown in figure III 1-8. The boot is about 0.075 inch (1.91 mm) thick except in the supply manifold area where it is 0.16 inch (4.1 mm) thick.

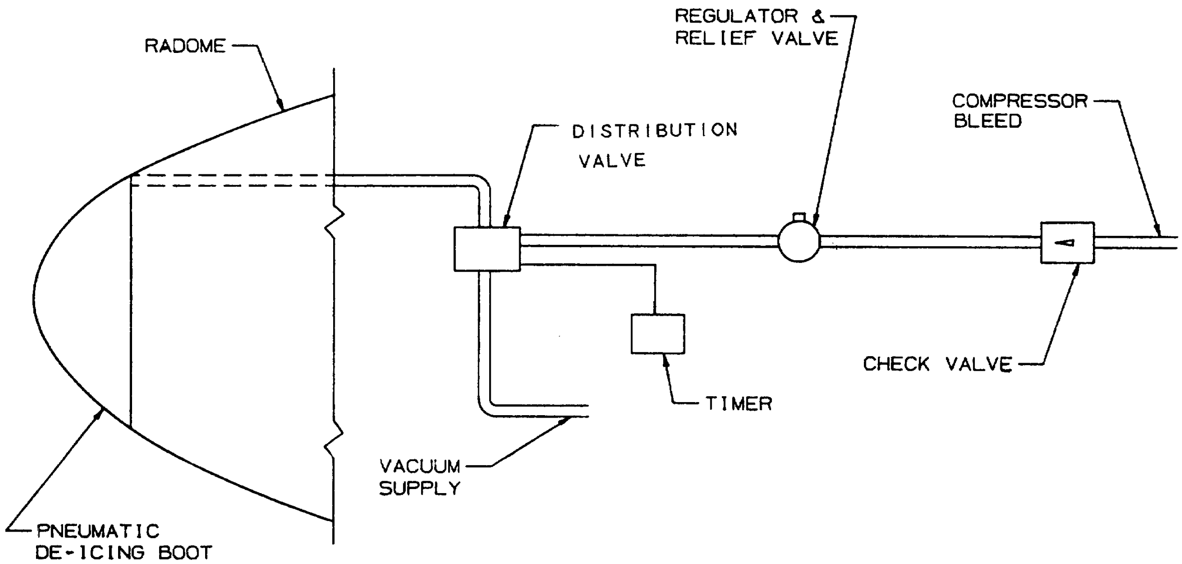


FIGURE III 1-7. PNEUMATIC BOOT DEICING SYSTEM—NOSE RADOMES

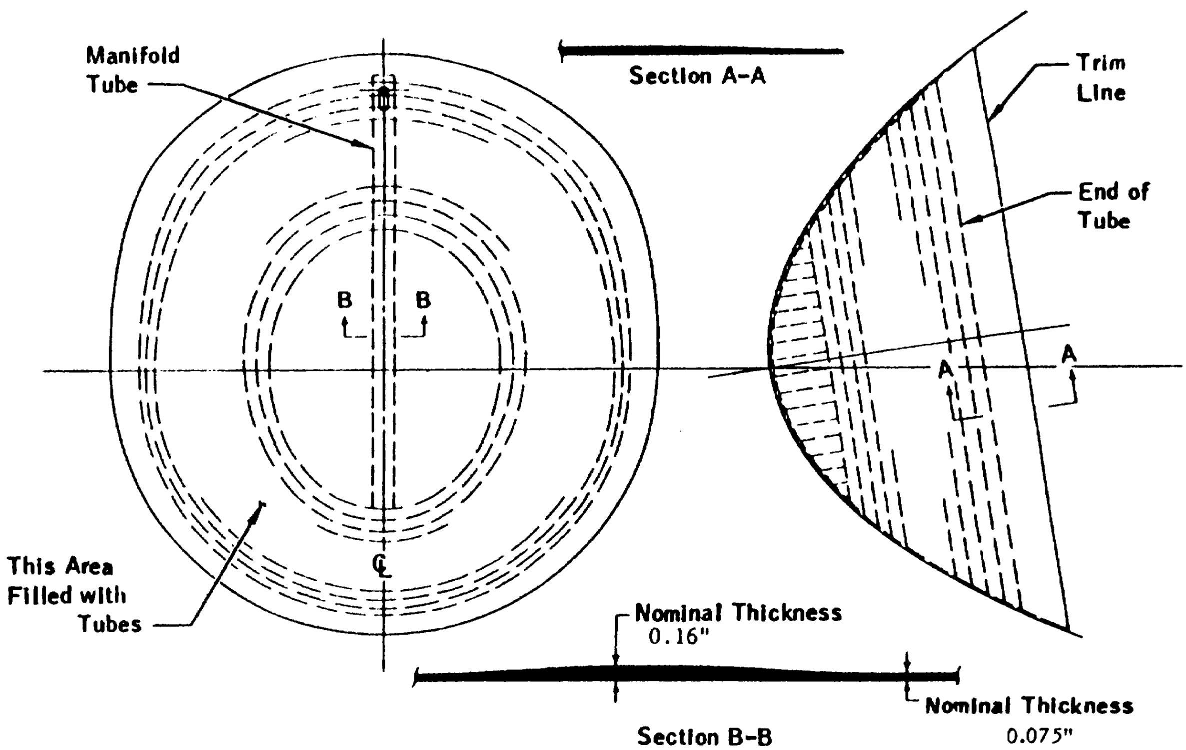


FIGURE III 1-8. TYPICAL NOSE RADOME DEICING BOOT CONFIGURATION

III.1.3.9 Miscellaneous Intakes and Vents.

Flush or recessed air scoops may not require ice protection. Pneumatic boot deicing of air intakes and vents may be feasible, depending on the size of the intake or vent, but no application is known.

III.1.4 WEIGHT AND POWER REQUIREMENTS.

The weight of a pneumatic boot ice protection system for a small, single-engine FAR Part 23 airplane is approximately 25 lb (11 kg) and requires about one-third horsepower (hp) (250 watts), intermittently. The distribution of the system weight should not significantly affect aircraft balance, and the total weight should not cause an appreciable performance penalty. The power extracted to drive an air pump in a piston engine-powered aircraft is small in relation to the total power available.

For a small, twin-engine FAR Part 23 airplane, a pneumatic boot ice protection system will weigh approximately 28 lb (12.5 kg) and require about one-half hp (370 watts), intermittently. The distribution of system weight should not significantly affect aircraft balance, and the total weight should not cause an appreciable performance penalty.

For a small twin-jet engine FAR Part 25 business jet airplane, a pneumatic boot ice protection system will weigh approximately 35 lb (16 kg) and require about one-half hp (370 watts), intermittently. For a large FAR Part 25 transport category airplane, the system will weigh approximately 195 lb (90 kg) and require about 2.8 hp (2100 watts).

For a 9500-lb (4310-kg) FAR Part 27 helicopter, a pneumatic boot deicing system (figure III 1-6) will weigh approximately 40 lb (18 kg). The weight breakdown of this system is inflatable boots 22 lb (10 kg), components 3.8 lb (1.7 kg), and plumbing 14.8 lb (6.7 kg). Operating air for a 2-second inflation cycle is about 22 ft^3 per minute. Electrical power required for this cycle is about one-half hp (370 watts), intermittently. For a larger FAR Part 29 transport category helicopter, the system weight and power required would be in proportion to aircraft weight.

III.1.5 ACTUATION, REGULATION, AND CONTROL.

A pneumatic boot deicing system is usually controlled by a three-position switch with OFF, MANUAL, and AUTO CYCLE modes of operation. When the switch is actuated in the MANUAL position, the deice system will operate through one cycle and return to the OFF position.

III.1.6 OPERATIONAL USE.

Preflight checkout of the pneumatic boot deicing system pressure and boot inflation is recommended. Generally, a nominal ice thickness of 0.5 inch is allowed to accrete before the deicing system is turned on.[1] Bridging is the formation of an arch of ice over the boot which is not removed by boot inflation. This can occur if the system is activated too early or too

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[1] For many aircraft with a pneumatic boot deicing system, the Aircraft Flight Manual (AFM) now requires that the system be activated at the first sign of ice formation anywhere on the aircraft or upon annunciation from an ice detector system, whichever occurs first; and that the system either continue to be operated in the automatic cycling mode, if available; or the system be manually cycled as needed to minimize the ice accretions on the airframe. The pilot must consult the AFM to determine the proper operation of the system.

frequently, especially in glaze icing conditions.[2] As icing encounters and severity of icing are difficult to forecast, the pilot should not depend upon marginal reserve power when ice protection is required and fly into an area where icing is predicted. Operation of a pneumatic boot ice protection system in ambient temperatures below -40°F (-40°C) may lead to permanent damage to the deicing boots.

Pneumatic boots should inflate and deflate rapidly to function effectively. To accomplish this, the time to reach full pressure should be about 5 to 6 seconds.

In tests to date on rotorcraft, the pneumatic boot system is activated when ice growth reaches approximately a 0.25-inch (6-mm) thickness or when the indicated torque increases noticeably above the level with no ice accretion. Rotorcraft typically have smaller airfoil chords than fixed-wing aircraft, so thick ice will result in high rotor power penalties, also thick ice may self-shed asymmetrically. The boot inflation time is approximately 2 seconds in rotorcraft applications.

An ice detection light is usually installed where it will illuminate a wing leading-edge surface as an aid in observing ice accumulation during night operation. The location of the light and area illuminated must be such that the pilot can readily observe ice accretion and its thickness.

Liquids that reduce ice adhesion (icephobic) are available for applying to boots prior to a flight when an icing encounter is likely. These sprays reduce the adhesion of ice to the boot surface resulting in improved deicing. However, the liquid erodes away so that it must be reapplied after 50 to 150 flight hours.

III.1.7 MAINTENANCE, INSPECTION, AND RELIABILITY.

Because pneumatic boot deicing systems operate on clean turbine engine bleed or filtered air from dry air pumps, little is required in servicing the system. All vacuum and pressure filters used in the system should be periodically cleaned. Frequency of this cleaning will vary with the conditions under which the airplane is operated.

The pressure regulating valves in the system ordinarily should not require adjustment, although the valve assembly will usually be equipped with adjusting screws to permit field adjustments.

The dry air pumps require no lubrication or maintenance but should be overhauled or replaced at engine overhaul.

Surfaces of the pneumatic boots should be inspected for engine oil after servicing and at the end of each flight. Any oil deposits should be removed with nondetergent soap and water solution. Care should be exercised during cleaning to avoid scuffing the boot surface. Pneumatic boots

[2] Ice bridging appears to be related to slow inflation and deflation rates of the deicing boot tubes, the boot system operating pressure, and the geometric characteristics of the deicing boot design, i.e., tube diameter, length, and orientation. Although commonly reported in the lore of flight of early piston-powered air transports, the FAA/NASA Deicing Boot Ice Bridging Workshop did not bring to light any documented reports of ice bridging for modern, properly functioning deicing boots.

may be damaged if refueling hoses are dragged over the surface of the boots or if ladders and platforms are rested against them. In any event, the boot manufacturer's recommendations should be followed for maintenance and repair of cuts and scuff damage.

III.1.8 PENALTIES.

Some aerodynamic drag penalty is to be expected with pneumatic boot deicing systems on an airfoil, but it can be lessened by recessing the surface leading edge to offset the boot thickness or eliminated by a molded deicer/composite leading-edge assembly.

III.1.9 ADVANTAGES AND LIMITATIONS.

Pneumatic boot deicing systems have been in use for many years and their repair, inspection, maintenance, and replacement are well understood (references 1-3, 1-4, and 1-5). System weight and power requirements are minimal. Pneumatic boot material deteriorates with time and periodic inspection is recommended to determine the need for replacement.

III.1.10 CONCERNS.

A certain degree of pilot skill is required for safe and effective pneumatic boot operation. Actuation when accreted ice is too thin may result in "bridging" where the formation of ice over the boot is not cracked by boot inflation. Thus, attention is required to judge whether the cycle time continues to be correct as icing conditions change. Demands on the pilot increase during flight in darkness since observation of ice accretion rate and severity is more difficult.[3]

III.1.11 REFERENCES.

1-1. Blaha, B.J. and Evanich, P.L., "Pneumatic Boot for Helicopter Rotor Deicing," NASA CP-2170, November 1980.

1-2. Haworth, L.A. and Oliver, R.G., "JUH-1H Pneumatic Boot Deicing System Flight Test Evaluation," USAAEFA Project No. 81-11, Final Report, May 1983.

1-3. Bowden, G.T., Gensemer, A.E., and Skeen, C.A., "Engineering Summary of Airframe Icing Technical Data," FAA ADS-4, December 1963.

1-4. Bowden, D.T., "Effect of Pneumatic De-Icers and Ice Formation on Aerodynamic Characteristics of an Airfoil," NACA TN 3564, February 1956.

1-5. Anon, "Deicing System. Pneumatic Boot, Aircraft General Specification for," Military Specification MIL-D-8804A, September 26, 1958.

[3] Refer to notes 1 and 2. The pilot must consult the AFM to determine the proper operation of the system. Ice bridging has not been documented for modern, properly functioning pneumatic deicing boots.

III.1.12 GLOSSARY.

Bridging—The formation of an arch of ice over a pneumatic boot on an airfoil surface.

Icephobic—A surface property exhibiting a reduced adhesion to ice; literally, “ice-hating.”

Light icing—The rate of accumulation may create a problem if flight is prolonged in this environment—over 1 hour. Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.[4]

Moderate icing—The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or diversion is necessary.[4]

[4] The FAA published new proposed definitions of light, moderate, and severe icing, as well as other icing terms, in the Federal Register, Vol. 65, No. 247, pp. 8094-8096, on Friday, December 22, 2000. Comments have been received, and the FAA is currently considering those comments.